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IMPACT OF EXTRUSION PROCESSION WEAR BEHAVIOR OF BORON NITRIDE REINFORCED ALUMINUM 6061-BASED COMPOSITES

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ABSTRACT

Aluminum (Al) 6000 alloy series are more industrial friendly among aluminum alloys since they are heat treatable and have superior formability. In the present experiment, Al 6061- boron nitride reinforced composites were developed by changing the boron nitride wt.% concentration. Composites samples were prepared for 3, 6 and 9 wt.% of boron nitride concentration. Boron nitride is used as reinforcement considering its superior hardness and thermal properties. The stir casting process is adopted for the fabrication of composites since it is a flexible and generally recognized method for developing castings economically. The prepared composites are successively hot extruded in nature. The extrusion process decreases defects in casting and modifies its grain structure resulting in an improvement in hardness and wear resistance. A metallographic study has done to determine the nature of boron nitride dispersion in matrix alloy. The microstructure photographs indicate the homogenous distribution of reinforcement in the Al6061 alloy. Study of hardness and wear resistance behavior has been carried out before and after extrusion. Al6061 -BN composites exhibited a decrease in wear rate compared to aluminum alloy. With an increase in sliding velocity and load, the wear rate of both aluminum alloy and composites increases, but when compared to conventional alloy the wear rate of in composite is less. The surface morphology has carried out on the worn out surface to identify the probable wear mechanisms.

Keywords: AL 6061, UTM, Wear Properties, Metal Matrix Composites, Boron Nitride, SEM & Hot Extrusion

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Original Article

INTRODUCTION

Aluminum matrix composites are the combination of particulate reinforcement and aluminum alloy in macro level. These combinations provide better performance in comparison with traditional aluminum alloy. Aluminum-based composites had widespread attention because of its high strength, ease of formability and resistance to wear [1]. Their tailored combination makes aluminum based particulate reinforced composites an attractive material for application in engineering. Among aluminum alloy, Al6061 has advantages such has good strength, excellent formability [2]. Further, its wear resistance can be improving by reinforcing it with much harder boron nitride [BN]. Various techniques such as stir casting [3], squeezed casting [4], mechanical alloying [5], liquid-solid powder metallurgy [6], etc., have been carrying out for the fabrication of composites. Among these

methods stir casting is chosen for preparation of Al 6061 -BN composites since, this method of preparation of composites is conventional, less time consuming, flexible compared to other methods [7, 8]. The secondary process like extrusion, rolling, forging, etc. refines the microstructure of the composites and improves its wear and mechanical properties making them considerable for automobile and space application [9, 10]. Al alloy reinforced with TiB_2 particles shows drastic improvement in wear resistance in comparison with aluminum alloy [11]. But Ma ZY *et. al.* [12] concluded that an increase in reinforcement, concentration rate of wear decreases. Furthermore, Venkataraman *et. al.* [13] studied wear characteristics of aluminum-Sic reinforced composites and found that, increase in the percentage of Sic reinforcement rate of wear decreases. Meanwhile, Shorowodi *et. al.* [14] have concluded that sliding wear behavior of aluminum - B_4C reinforced composites and Aluminum-Sic reinforced composites noticed the creation of phenolic layer developed at the interface of composites during sliding against the break pad. Which is protects the composites against the plastic deformation leading to a reduction in wear rate from the light of published data. It is has been observed that meager experimental work has been conducted on wear studies of extruded Al composites, hence present work focuses on the experimental determination of wear behavior of casted and extruded Al 6061-BN reinforced composites.

METHODOLOGY

Casting and Extrusion Process

For prepare Al-6061-BN composites, firstly calculated quantities of Al-6061, placed in a graphite crucible and melt it. Degassing of the melt has done by using hexachloroethane tablets before adding boron nitride reinforcement particles. Pre-heating of the reinforcement particles to a temperature at 200 °C before charging into the vertex of the molten matrix. The vertex in the melt was created by stirring the melt at 400 rpm with the help of stirrer immersed approximately 2/3 depth of molten melt. The composites were prepared by varying the reinforcement percentage has 3 wt.%, 6 wt.% and 9 wt.%. Melted composites elevated to a temperature at 740°C and it transferred on to cast iron mold having diameter 35 mm and 40 mm length. Detailed explanations on the preparation of composites are explained [15, 16]. The casted specimens have subjected to hot extrusion. The casted and hot extruded specimens are subjected to microstructure studies to determine the extent of distribution. Table 1 represents chemical constituents of Al 6061 alloy. The casted specimen having a specific dimension of 35 mm diameter and 40 mm length has maintained at the temperature at 560 °C before placed in a preheated extrusion die maintained at the temperature of 480-500 °C. The inner surface of extrusion die has lubricated with the help of graphite powder and grease mixture. To extrude the specimen load is applied on the punch gradually with help of UTM. Figure1 shows a photographic view of the extrusion dies during an extrusion process. Figure 2 shows a photographic view of the extruded specimen.

Table 1: Chemical Constituents of the Pure Al-6061 Alloy

Sl. No.	Elements	%
1	Ti	0.013
2	Mg	0.81
3	Cu	0.36
4	Sn	0.015
5	Fe	0.146
6	Zn	0.01
7	Pb	0.02
8	Si	0.87
9	Mn	0.036

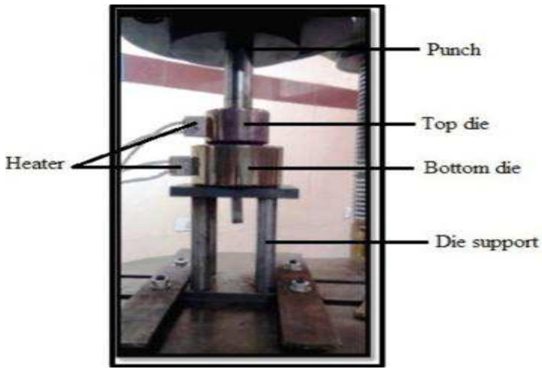

Figure 1: Extrusion Die

Figure 2: Extruded Rod

RESULTS AND DISCUSSIONS

Optical Micro-Structural Studies

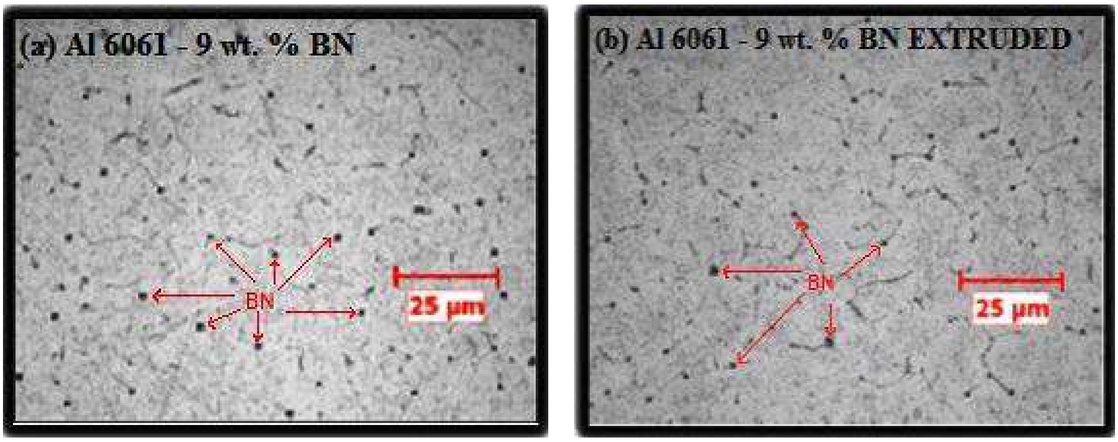

Figure 3: Optical Photographs of Casted and Extruded AL 6061-BN Composites

Figure 3 shows optical microstructure photographs of 6061Al with 9 wt. % BN casted (Figure 3a) & 6061Al with 9 wt. % BN extruded (Figure 3b). 9 wt. % BN extruded samples shows fine precipitate of reinforcement particles in comparison to 9 wt % BN casted sample. Extruded optical photographs show less voids in comparison. Moreover, the figures indicate that the BN particles are homogeneously distributed all along gain boundaries of the matrix.

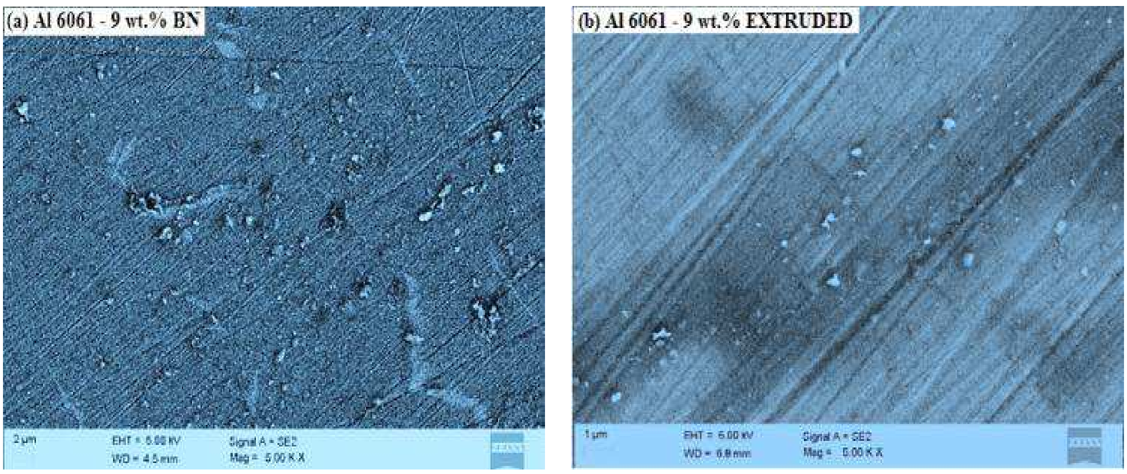

Figure 4: Casted and Extruded Specimens SEM Microphotographs

Figure 4 shows scanning electron microscope (SEM) microphotographs of casted and extruded composites. It is evident from photographs that there is fairly homogeneity in reinforcement distribution. The density equivalence of boron nitride reinforcement results in superior bonding. The SEM of extruded composite shows the reinforcement alignment in the extrusion direction [17]

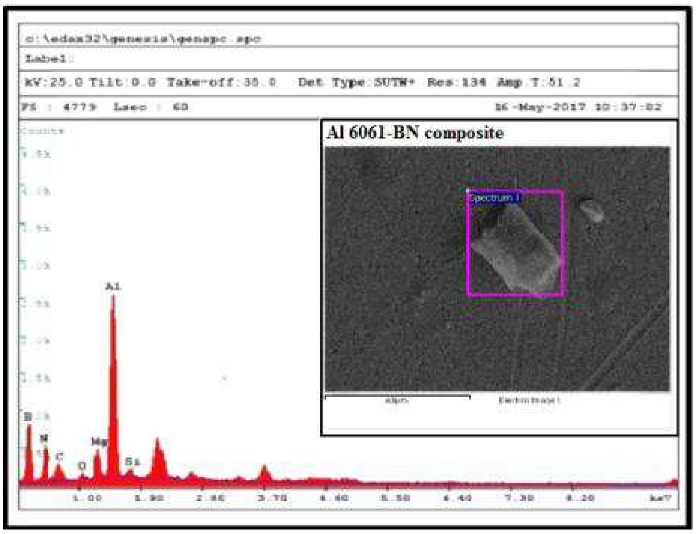

Figure 5: EDX Enclosed Al 6061-BN Composite

Figure 5 shows Energy dispersive X-ray spectroscopy (EDX) result of Al 6061-BN composite. It has shown good bonding between reinforcing particles and matrix alloy and developed aluminum matrix composite.

Micro-Hardness

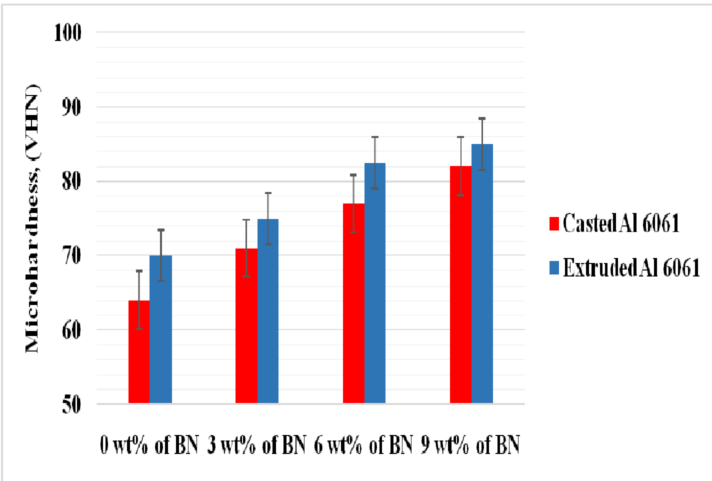

Figure 6: Micro Hardness Variations of Casted and Extruded Specimens

Figure 6 compares the hardness variation between casted and hot extruded Al 6061-BN composites. The casted and hot extruded specimens where subjected to micro-hardness studies. The hardness of specimens was found and averaged by placing the test indenter at different places to avoid the indenter placing on much harder BN reinforcement particles. The experimentation indicates improvement in hardness of casted and extruded samples with an increase in BN reinforcement concentration. Following are the reasons for the improvement in hardness number of Al6061-BN composites.

- BN reinforcement particles are much harder than Al matrix alloy.
- With a higher proportion of BN reinforcement in the Al6061 alloy, a large percentage of indenter pressure will be shared by harder BN particles which leads to an increase in the hardness of composites.
- A decrease in the porosity of castings with an escalation in quantity of reinforcement.

Further extruded composites show better hardness in comparison since the extrusion process refines the gain structure and reduces the porosity of composites.

Wear

Wear characterization of casted and extruded composites were carried out with the pin and disc equipment. Specimens having a diameter of 10 mm and length of 25 mm were used as test samples. The prepared specimens are loaded against the rotating disc made up of EN 31 steel and having hardness 56-58 HR. the track radius was maintained 30 mm and all experiments are performed in room condition. The prepared samples are subjected to sliding wear test to analyze the influence of BN adding on wear behavior of Al alloy. The wear rate is calculated on the percentage of weight loss basis. Figure 7 shows the top view of the equipment used to carry out wear studies. Figure 8 shows prepared casted specimens used to carry outwear test

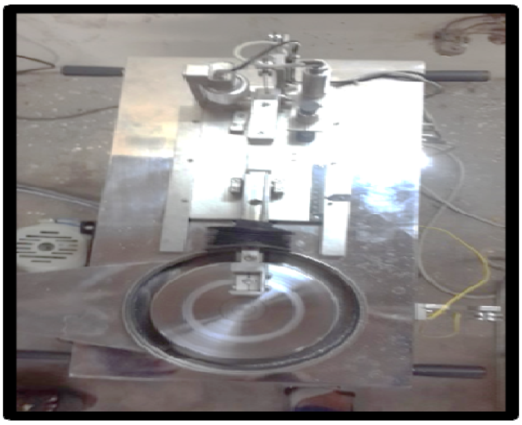

Figure 7: Wear Testing Equipment

Figure 8: Casted Specimen

Effect of BN Reinforcement

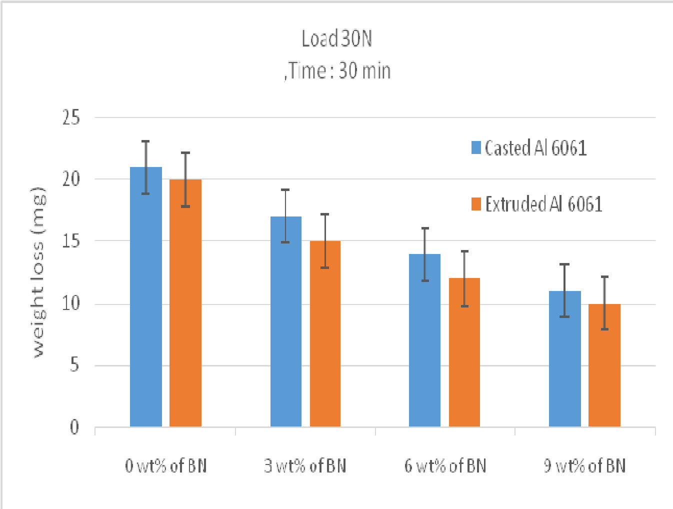

Figure 9: Wear rate Variation of Casted and Extruded Al 6061-BN Composites Under Constant Loading Condition

Figure 9 shows the response of casted and extruded specimen for the rate of wear. The casted and hot extruded samples were subjected to wear test. Test were carried out under the condition of the constant load. The prepared specimens are loaded and pushed against the rotating disc. The load was maintained constant at 30 N and test was conducted to the duration of 30 min at room temperature condition. The composite samples exhibited a reduction in wear rate up to 50% in Al 6061-9wt% BN composites in contrast with Al 6061 alloy. The comparative study was made between casted and extruded samples. Extruded samples displayed a lower wear rate in comparison. It can be noted that there is a gradual reduction in wear resistance with increasing load. At higher loads the composites plastically deform resulting in increased wear rate.

Effect of Load

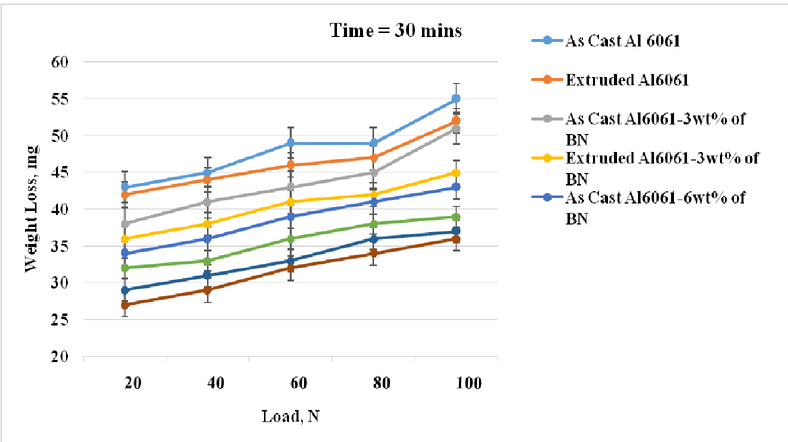

Figure 10: Wear Rate Variation of Casted and Extruded Al 6061-BN Composites Under Different Loading Condition

Figure 10 shows wear behavior of composites under different loading condition. The prepared composite specimens are loaded and punched against the rotating disc made up of EN 31 steel and having hardness 56-58 HRC. The experiment is performed at room temperature in a load range of 20 to 100 N. It can be noticed that there is a gradual

reduction in wear resistance with increasing load. The harder BN particle obstructs the penetration of abrasive particles of disc surface resulting in a reduction in weight loss. In case of composites with a higher percentage of reinforcement major portion of the load is taken by reinforcing particles acting as an obstacle against wear. Improved wear resistance is observed in extruded composites this is due to the reduction in porosity and grain refinement [18, 19]

Surface Micrograph of the Worn Surface

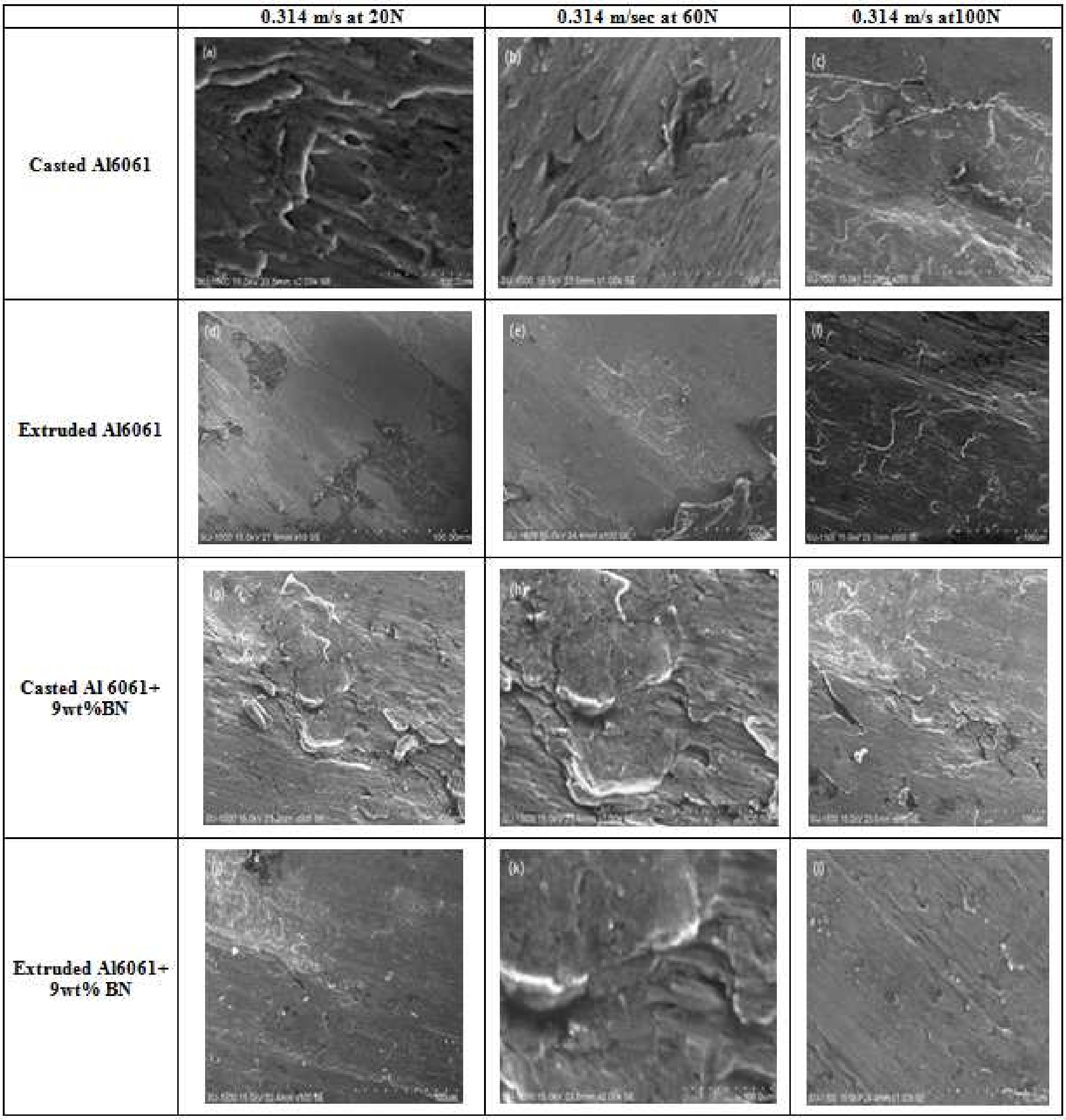

Figure 11: Worn Surface Photographs of Al6061 Alloy (a-c), Al6061-BN Composites (d-f), Extruded Al6061 Alloy (g-h) and Extruded Al 6061 -BN Composites (i-k) at Different Sliding Velocity

Figure 11 (a-c) and figure 11 (g-i) shows worn surface photographs of casted Al 6061 alloy and Al6061-BN composites respectively at different sliding velocity. From the photographs, it can be noticed that the surface morphology of the un-reinforced alloy defers from that of the morphology of composites. Un-reinforced alloy figure 11 (a-c) shows the presence of wide and deeper grooves on its surface whereas composites figure 11 (g-i) shows fine grooves on its surface.

The reduction in plastic deformation in composites is attributed to the presence of wear debris in its morphology along the sliding direction. The debris is the combination of fractured reinforcement particles, matrix material, and steelcounter face. These debris gets oxidized during sliding due to heat generation and acts as the counter face against the rotating disc leading to a reduction in wear rate [19]. The extruded composites figure 11 (j-l) morphology shows relatively smooth and thin surface in comparison with casted composites at all sliding velocities. This finding reflects a lower rate of wear in extruded composites in comparison with casted composites [20]. At higher sliding velocity [1.574 m/s] both casted and extruded composites experience greater plastic deformation due to the reduction in hardness of protective mechanical mixed layer has reported by many researchers [21].

Figure 12 (a-c) and figure 12 (g-i) shows worn surface photographs of casted Al 6061 alloy and Al6061-BN composites respectively at different loading conditions. It is evident from the photographs that the morphology of casted alloy figure 12 (a-c) exhibits larger grooves on its surface due to plastic deformation whereas morphology of composites figure 12 (g-i) exhibits fine grooves on its surface.

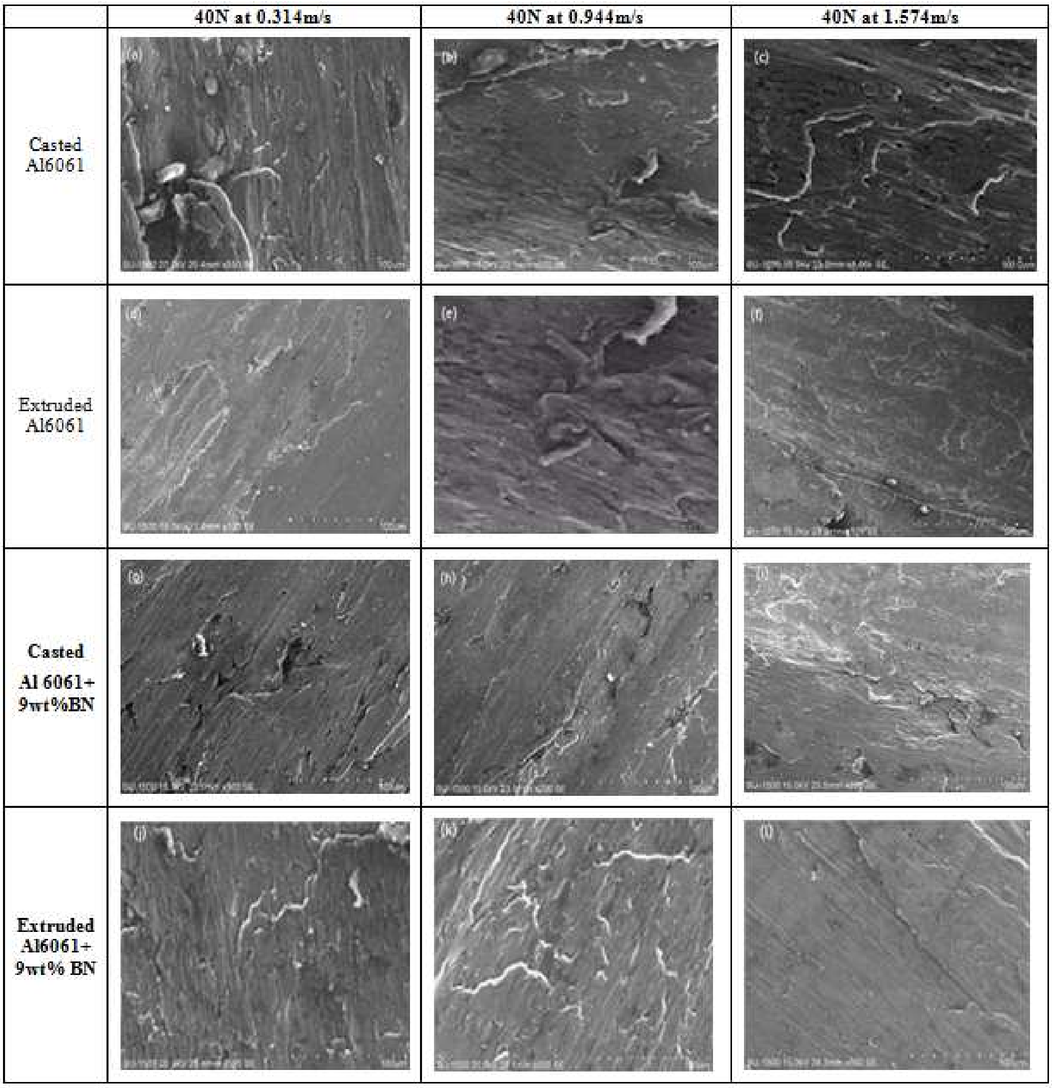

Figure 12: Worn Surface Photographs of Al6061 Alloy (a-c), Al6061-BN Composites (d-f), Extruded Al6061 Alloy (g-h) and Extruded Al 6061 -BN Composites (i-k) at Different Loads

The reinforcement particles in case of composites act as the obstacle for plastic deformation resulting in a reduction in wear rate due to heat generation [22]. It can be observed that maximum plastic deformation in case of both alloy and composites happens at higher loads (100N) [23]. However, extruded composites figure 13 (j-k) exhibits lesser plastic deformation in comparison. The extrusion process modifies the grain structure of casted composites and increases its hardness [20]. it is evident from the photographs figure 13 (j-l) that morphology of extruded specimens shows minimal grooves and micro-cracks on its surface. The surface morphology photographs have no evidence of reinforcement particle pull out which indicate the strong bonding between reinforcement particles and matrix.

CONCLUSIONS

The fabrication of Aluminum - 6061 based BN reinforced composites have been carried out by a stir casting method and extruded successively. Scanning electron microscope analysis conforms that the reinforcement particles are distributed uniformly in the aluminum matrix. Casted composite exhibits an enhancement in mechanical and tribological properties such as hardness and wears resistance with an increase in the percentage of reinforcement (BN) concentration in the aluminum matrix. Extruded Al 6061-BN has shown excellent resistance against wear rate and improved hardness in contrast with casted Al 6061-BN composites. Over-all study indicates the composites developed shows better strength and lower wear rate to that of Al 6061 alloy.

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